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PERFORMANCE OF SOILS VERSUS CHEMICAL PROPERTIES

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PERFORMANCE OF SOILS VERSUS CHEMICAL PROPERTIES

C. Kinney Hancock[1]

SYNOPSIS

Some soils exhibit traffic-bearing characteristics contrary to those predicted from physical test data. Toward reducing the economic loss from the use or non-use of such soils, the soil colloid silica-sesquioxide ratio has been proposed as a supplementary index to roadbed performance.

The previous reported correlation between roadbed performance and soil colloid silica-sesquioxide ratio does not apply to Texas caliches. However, it is believed that the correlation may apply to other soil types. The silica-sesquioxide ratio does not vary appreciably over the particle size range of 0.1-3 microns. The double percentage ratio, 2 x % SiO_2/% R_2O_3, may be substituted for the molecular SiO_2/ (Al_2O_3 + Fe_2O_3) ratio. Calculation of the former ratio is easier and does not require determinations of iron and titanium.

These simplifications should be of value in further studies of the relation between chemical properties of soils and roadbed performances.

INTRODUCTION

During the past two decades, considerable progress has been achieved in the development of physical test procedures for the evaluation of soils as subgrade and base materials for use in highway construction. Various procedures for physical tests have been devised and improved, and the physical data resulting from the application of such tests have been of great value in classifying materials as to quality. In the large majority of cases, the quality of a soil as predicted from its physical characteristics has been substantiated by its performance after being used in a roadbed.

As a result of the complex nature of soils and of the many, and sometimes abnormal or unforeseen, factors involved in highway construction, anyone should expect to find exceptions to this good general correlation. Two classes of exceptions that have arisen are: the case of materials with poor physical constants which prove satisfactory and that of materials with good physical constants which are found to be unsatisfactory.

The latter class of exceptions may appear, on first thought, to be much more serious since the use of such soils because of their good physical constants would result in the failure of the road, thereby entailing considerable economic loss. On the other hand, the rejection of a

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soil of the former class because of its poor physical constants might result in the necessity of transporting an apparently more suitable soil over a much greater distance to the right-of-way, which would also be costly. Consequently, either class of exception may assume considerable economic importance.

Several new or revised supplementary methods have been proposed for further minimizing the number of exceptional cases as described above. One method of attack on this problem has been through studies of the chemical properties and composition of soils which are closely associated with the physical characteristics of such materials.

As one consequence of this recent trend of soils investigation, the silica-sesquioxide ratio of the colloid fraction has been proposed as an index to the quality of the corresponding soil. It has been shown (6, 13) that the properties of soil colloids vary fairly regularly with the SiO_2 / (Al_2O_3 + Fe_2O_3) ratio and it has been found (13) that soil colloids having a ratio less than 1.85 were from localities having forty or more inches of rainfall annually. Joseph and Hancock (9) classified soils according to silica-alumina ratios as follows: less than 3, non plastic (kaolinite); 3-5, intermediate; more than 6, extremely plastic (bentonite). Dennison (5) examined the colloids from several soil profiles and found that the molecular silica-sesquioxide ratio decreased regularly with depth. Baver and Scarseth (2) found that colloidal material of high silica-sesquioxide ratio tends to be more highly buffered, to exhibit stronger acidity, and to have a higher exchange capacity than colloids having a low ratio. Russell (14), in summarizing the work of previous investigators, states that the typical clay properties all increase as the SiO_2/R_2O_3 ratio increases from two to six or seven (podsols) but do not usually appear when the ratio is two or less (laterites). Jewett (8) found that clays with high SiO_2/R_2O_3 ratio s absorb much larger volumes of water than of toluene, while clays with ratios of about two or less absorb slightly more toluene than water.

For nineteen soil-aggregate base-course materials from Georgia and Alabama, Rapp and Mizroch (11) found a good correlation between the silica-sesquioxide ratio of the colloid fraction and the known roadbed performance of the corresponding soil. This relationship is shown in Figure 1 by a graphical method not employed by Rapp and Mizroch.

In view of the good general correlation found by Rapp and Mizroch, it was decided to undertake a similar study of Texas caliches (3, 7) of known roadbed performance. Accordingly, seven caliche samples were selected for investigation, including four exceptional samples. The performance and physical test data of these samples are given in Table I. The soil constants were determined by the official procedures of the Texas Highway Department which conform generally to those of the American Association of State Highway Officials (1).

The colloid fractions of these samples were extracted and prepared for analysis in a manner similar to that of Rapp and Mizroch (11), except for the two variations noted below. Whereas, Rapp and Mizroch separated the colloid fraction (particles smaller than 1 micron) by passing a suspension of minus 270-mesh material through a continuous supercentrifuge; in this study, a suspension of minus 270-mesh material

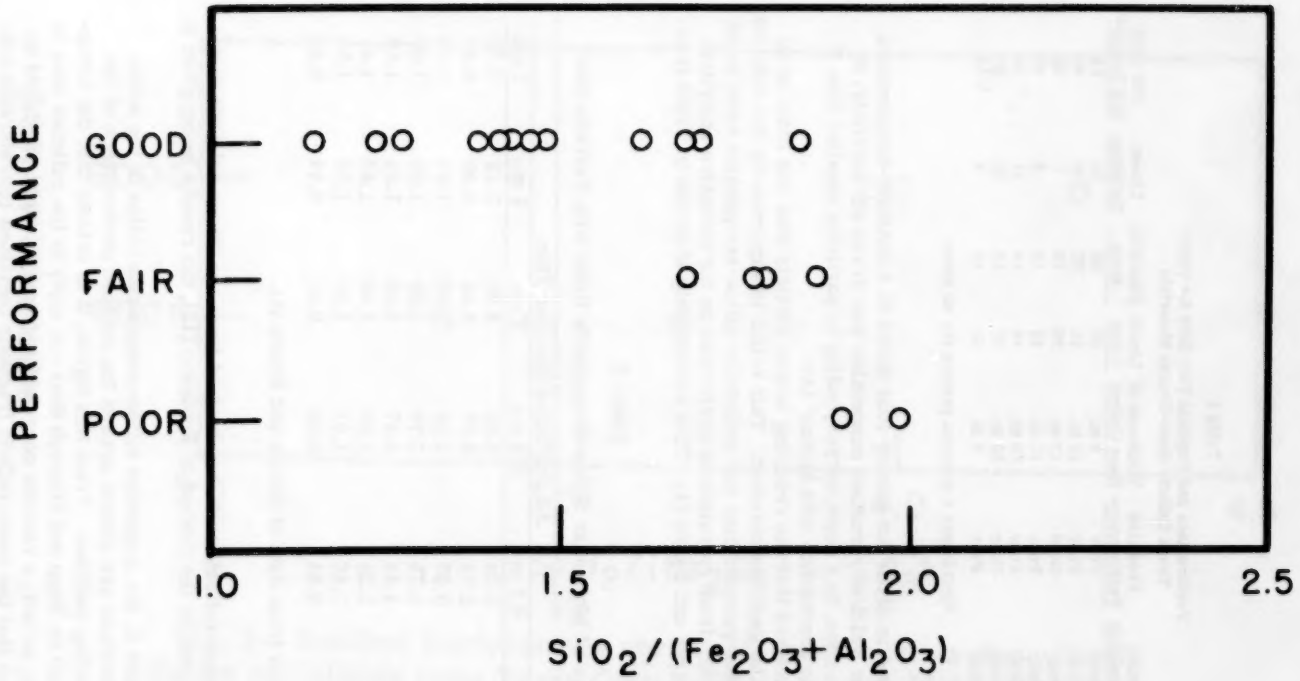


Fig.1— Roadbed Performance versus Molecular Silica-Sesquioxide Ratios of Colloids from Alabama and Georgia Base-Course Materials. Data of Rapp and Mizroch (11).

Table I

Performance and Physical Test Data for Seven Texas Caliche Base-Course Materials

Soil No.	Actual Performance	Predicted Performance	Thickness of Base Course	Liquid Limit	Plasticity Index	Linear Shrinkage	Per Cent Soil Binder[a]
1	Good	Poor	8 in.	45	26	13	54
2	Poor	Poor	10 in.	51	27	14	45
3	Poor	Good	12 in.	29	12	7	43
4	Poor	Poor	12 in.	42	19	9	45
5	Good	Poor	10 in.	40	19	11	59
6	Good	Poor	10 in.	37	18	10	63
7	Poor	Poor	8 in.	28	15	8	74

[a]Soil binder = material passing No. 40 sieve.

was allowed to settle for twenty-four hours in a constant-temperature room after which supernatant suspension was drawn off carefully, by surface suction, to a depth corresponding to particles smaller than 2 microns in accordance with Stokes' law.

It is believed that the resulting larger particle size has little or no effect on the analyses obtained. This belief is supported by the relationship between particle size and molecular silica-sesquioxide ratio found by the writer from calculations performed on the extensive analytical data of Brown and Byers (4). This relationship is shown in Table II below.

Table II

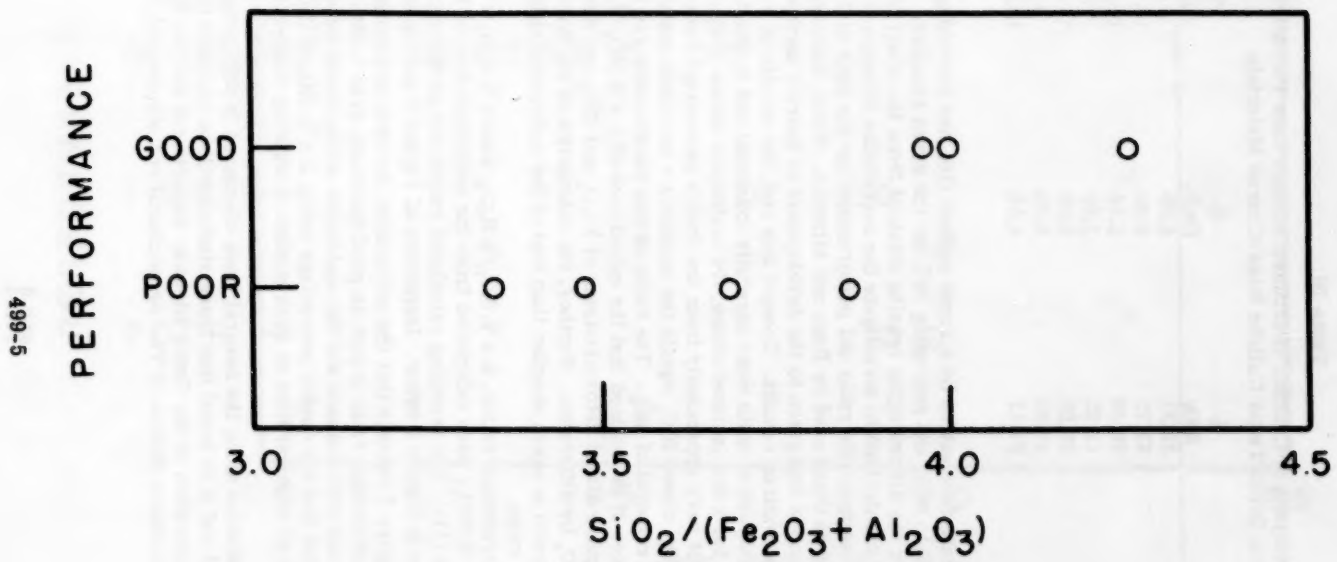
Variation of Molecular Silica-Sesquioxide Ratio with Particle Size[a]

	All Particles Smaller Than				
Lab. No.	0.1 mu	0.3 mu	1 mu	2 mu	3 mu
4575	3.04	3.04	3.08	3.12	3.16
191	2.74	2.77	2.84	2.90	2.95
4447	0.97	1.17	1.43	1.46	1.49
6263	1.75	1.70	1.69	1.69	1.69
4440	1.46	1.47	1.49	1.51	1.55
6278	1.36	1.36	1.40	1.40	1.41
6274	1.46	1.61	1.59	1.58	1.56
6281	0.44	0.38	0.42	0.44	0.46

[a]Calculated from data of Brown and Byers (4).

The seven colloid fractions obtained from the Texas caliches were then analyzed by the method of Robinson (12), the results being given in Table III.

In Figure 2, the molecular silica-sesquioxide ratios of the seven colloid fractions are plotted against the roadbed performance of the corresponding caliches. From this figure, it is evident that the correlation found by Rapp and Mizroch does not apply to the caliches used in this study; in fact, a reverse correlation seems to apply. It should be pointed out that the seven colloid fractions contained considerable cal-



499-5

Fig. 2— Roadbed Performance versus Molecular Silica-Sesquioxide Ratios of Colloids from Texas Caliche Base-Course Materials.

Table III

Chemical Analyses of Colloids (Particles Smaller than Two Microns) from Seven Texas Caliche Base-Course Materials

Soil No.	% SiO_2	% Fe_2O_3	% Al_2O_3
1	29.31	4.09	9.08
2	45.75	6.40	16.07
3	28.68	4.16	11.34
4	18.25	1.86	7.24
5	26.88	3.92	9.02
6	27.82	3.88	9.32
7	27.41	4.56	10.98

cium carbonate determined by a rapid method (10), the percentage varying from 22% to 68%, and averaging 50% for the seven samples.

In spite of the discouraging results obtained from the study of caliches, it was decided to investigate the correlation between the molecular silica-sesquioxide ratio and performance for the case of Texas soils similar to those used by Rapp and Mizroch. First, however, considerable thought was given to the development of shorter methods for achieving the desired results. Toward this end, the results of many published analyses of soils were carefully examined and it was found that, except for a few isolated cases, the molecular silica-sesquioxide ratio does not vary appreciably from the double percentage ratio, 2 x % SiO_2/% R_2O_3, where R_2O_3 equals the ammonia - insoluble material obtained after removal of SiO_2. The value of this relationship can be appreciated when it is realized that the calculation of 2 x % SiO_2/% R_2O_3 does not require direct determinations of Fe_2O_3 and TiO_2 and determination of Al_2O_3 by difference. Further, the calculation of the double percentage ratio is much simpler than that of the molecular silica-sesquioxide ratio.

Double percentage ratios, 2 x % SiO_2/% R_2O_3, where % R_2O_3 = % Fe_2O_3 + % Al_2O_3 + % TiO_2, were calculated from the analytical data of Rapp and Mizroch (11). The resulting calculated ratios are plotted against performance in Figure 3 below. Inspection of Figure 3 and comparison of it with Figure 1 reveals that the correlation between performance and the double percentage ratio is just as good (perhaps, even a little better) as that between performance and the molecular silica-sesquioxide ratio. It is concluded that the double percentage ratio, 2 x % SiO_2/% R_2O_3, is quite worthy of consideration in such studies of highway base-course materials.

Further studies along the several lines discussed in this article have been planned and it is hoped that these studies will be realized through the joint cooperation of the Texas Highway Department and the Engineering Experiment Station of The Agricultural and Mechanical College of Texas.

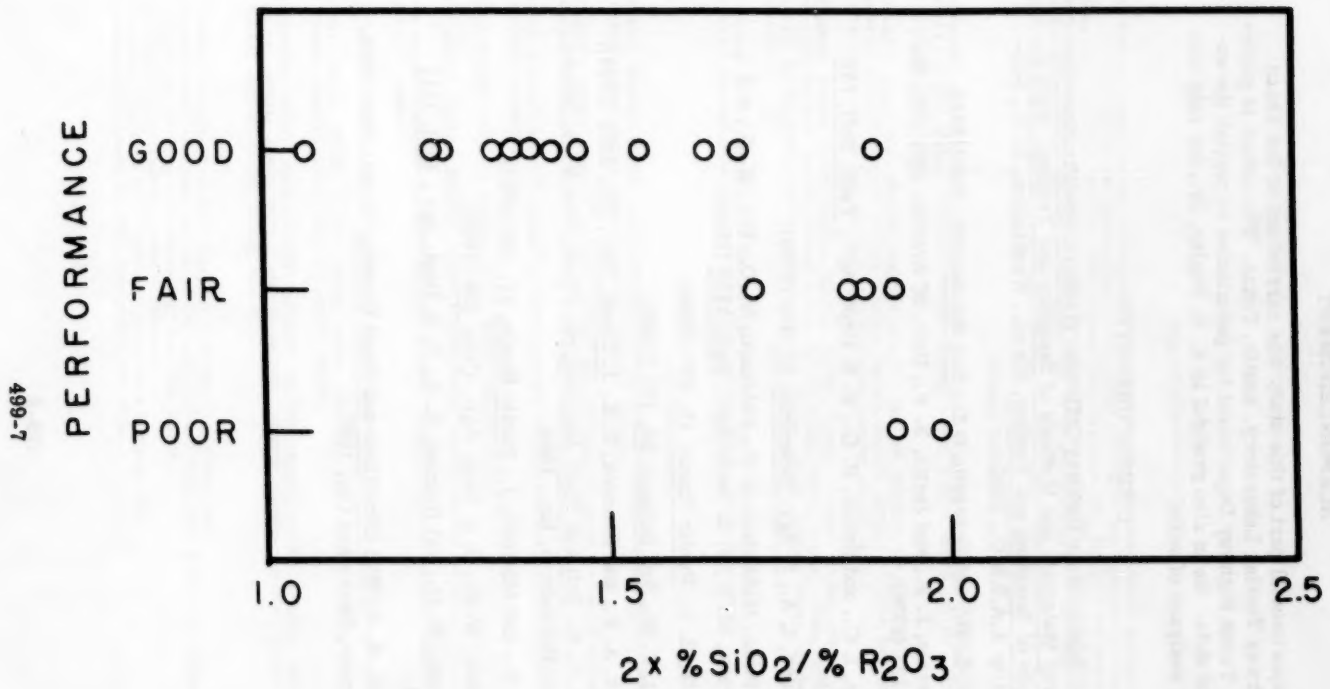


Figure 3. Roadbed Performance versus Double Percentage Ratios, 2 x $\% SiO_2/\% R_2O_3$, of Colloids from Alabama and Georgia Base-Course Materials. Calculated from data of Rapp & Mizroch (11).

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VOLUME 80 (1954)

JANUARY: 379(SM)[c], 380(HY), 381(HY), 382(HY), 383(HY), 384(HY)[c], 385(SM), 386(SM), 387(EM), 388(SA), 389(SU)[c], 390(HY), 391(IR)[c], 392(SA), 393(SU), 394(AT), 395(SA)[c], 396(EM)[c], 397(ST)[c].

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AUGUST: 466(HY), 467(HY), 468(ST), 469(ST), 470(ST), 471(SA), 472(SA), 473(SA), 474(SA), 475(SM), 476(SM), 477(SM), 478(SM)[c], 479(HY)[c], 480(ST)[c], 481(SA)[c], 482(HY), 483(HY).

SEPTEMBER: 484(ST), 485(ST), 486(ST), 487(CP)[c], 488(ST)[c], 489(HY), 490(HY), 491(HY)[c], 492(SA), 493(SA), 494(SA), 495(SA), 496(SA), 497(SA), 498(SA), 499(HW), 500(HW), 501(HW)[c], 502(WW), 503(WW), 504(WW)[c], 505(CO), 506(CO)[c], 507(CP), 508(CP), 509(CP), 510(CP), 511(CP).

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b. Beginning with "Proceedings-Separate No. 290," published in October, 1953, an automatic distribution of papers was inaugurated, as outlined in "Civil Engineering," June, 1953, page 66.
c. Discussion of several papers, grouped by Divisions.
d. Presented at the Atlanta (Ga.) Convention of the Society in February, 1954.
e. Presented at the Atlantic City (N.J.) Convention in June, 1954.

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